NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

AD-A257 336

THESIS

OPTIMAL LINEAR ARRAY HEADING
IN A DIRECTIONAL NOISE FIELD

by

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September 1992

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92-29919

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.			
2b. DECLASSIFICATION DOWNGRADING SCHEDULE						
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School		6b. OFFICE SYMBOL (If Applicable) 3A	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School			
6c. ADDRESS (city, state, and ZIP code) Monterey, CA 93943-5000			7b. ADDRESS (city, state, and ZIP code) Monterey, CA 93943-5000			
8a. NAME OF FUNDING SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If Applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8c. ADDRESS (city, state, and ZIP code)			10. SOURCE OF FUNDING NUMBERS			
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
OPTIMAL LINEAR ARRAY HEADING IN A DIRECTIONAL NOISE FIELD

12. PERSONAL AUTHOR(S)
David C. McDonnell

13a. TYPE OF REPORT Master's Thesis	13b. TIME COVERED FROM TO	14. DATE OF REPORT (year, month,day) September 1992	15. PAGE COUNT 58

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17.	COSATI CODES		18. SUBJECT TERMS (continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUBGROUP	Linear Arrays, Directional Ambient Noise, Optimal Signal-Noise Ratio

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This thesis discusses a procedure that optimizes the signal-to-noise ratio (SNR) detected by a linear array in a directional ambient noise field. The SNR can be optimized by minimizing the ambient noise detected by the array. For a given target location, each possible heading of the array centers the ambiguous beam of the array at a different true bearing. Therefore, each heading of the array will receive a different ambient noise level. An optimal heading can be obtained which maximizes the SNR received by the array. For all possible headings the beam pattern of the array must be determined and combined with the ambient noise field to determine the noise level detected. This thesis discusses the theory involved in calculating the ambient noise levels detected for each heading and provides a computer program which performs the calculations for a particular array.

20. DISTRIBUTION AVAILABILITY OF ABSTRACT [X] UNCLASSIFIED UNLIMITED [ ] SAME AS RPT. [ ] DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Alan B. Coppens	22b. TELEPHONE (Include Area Code) 408-646-2941	22c. OFFICE SYMBOL PH

DD FORM 1473, 84 MAR   83 APR edition may be used until exhausted   SECURITY CLASSIFICATION OF THIS PAGE
All other editions are obsolete   Unclassified

Optimal Linear Array Heading
in a Directional Noise Field

by

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Lieutenant, United States Navy
B.S., United States Naval Academy, 1985

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF APPLIED SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
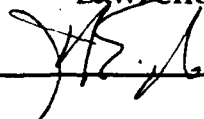September, 1992

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ABSTRACT

This thesis discusses a procedure that optimizes the signal-to-noise ratio (SNR) detected by a linear array in a directional ambient noise field. The SNR can be optimized by minimizing the ambient noise detected by the array. For a given target location, each possible heading of the array centers the ambiguous beam of the array at a different true bearing. Therefore, each heading of the array will receive a different ambient noise level. An optimal heading can be obtained which maximizes the SNR received by the array. For all possible headings the beam pattern of the array must be determined and combined with the ambient noise field to determine the noise level detected. This thesis discusses the theory involved in calculating the ambient noise levels detected for each heading and provides a computer program which performs the calculations for a particular array.

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The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

The collapse of the Soviet Union and the distribution of diesel submarines to many third world countries have significantly changed the Antisubmarine Warfare (ASW) problem for the United States and its allies. The open ocean, deep water ASW scenario versus Soviet nuclear powered submarines has been replaced by what most experts agree to be a shallow water scenario against quiet diesel powered submarines. Additionally, improvements in submarine sound silencing throughout the world have drastically reduced passive acoustic detection ranges. The change in the ASW problem and the improvements in sound silencing on submarines has forced the United States to investigate new methods to increase passive detection ranges while maintaining the tactical advantage.

The success or failure of a tactical towed array to detect a target of interest often depends on the signal-to-noise ratio (SNR) received at the sensors making up the array. Any opportunity to increase the SNR should be taken advantage of to increase the probability of detection. One viable means of increasing the SNR is to reduce the ambient noise detected by the array. The ambient noise detected by the array can often be reduced by exploiting the ambient noise field directionality by orienting the array in the optimal direction. For a suspected target location, each array heading centers the ambiguous beam (See Section IVA) at a different true

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bearing. Therefore, each heading will receive a different ambient noise level. By combining the beam pattern of the array with the ambient noise field for all possible array headings, an optimal heading can be obtained which minimizes the noise level detected by the array.

The majority of environmental models existing in the fleet today assume an omnidirectional ambient noise field. In many areas of the ocean the omnidirectional model is sufficient, while in other areas, including those close to shore and shipping lanes, the ambient noise level varies significantly with true bearing in the frequency spectrum dominated by distant shipping. The directionality of ambient noise can be used to the tactical advantage of the operator by orienting the linear array in a manner which aligns the ambiguous beam so that the total ambient noise received on beams directed towards the suspected location of the target is minimized. Linear array beam pattern calculations and the interaction of these patterns with the ambient noise field are discussed in detail in this thesis. Additionally, a computer program is provided which performs all the necessary calculations for a particular array. The program is limited to a single frequency and the target's suspected location must be known prior to running the program. The program is provided to demonstrating the feasibility of constructing a program for each tactical towed array in the Navy's arsenal.

II. HORIZONTAL DIRECTIONALITY OF AMBIENT NOISE

A. SOURCES OF DIRECTIONAL AMBIENT NOISE

The horizontal directionality of ambient noise is caused by numerous sources including rain storms, biologics, and distant shipping. Most of these sources have short propagation ranges and rarely affect the directionality of ambient noise detected by passive acoustic sensors except for distant shipping. The frequency range in which distant shipping is the principle source, and therefore subject to high levels of directionality, is from about 50 to 500 Hz. [Ref. 1]. Within this frequency range the ambient noise can be dominated by noise which can travel for distances of 1000 miles or more from the location of the sensor by way of refracted raypaths in the deep sound channel. In this case, the ambient noise often has a distinct directional character with noise levels varying between true bearings. It is also within this frequency range that many passive acoustic sensors can detect enemy submarine signatures including blade rate information.

There are two major mechanisms which account for the sound of distant shipping being trapped in the deep sound channel and therefore contributing to the directional character of the ambient noise field. The first mechanism is the tendency of the deep sound channel to approach the surface as the latitude increases [Ref. 2]. As can be seen in Figure 1, the depth of the deep sound channel in the

Pacific Ocean ascends toward the surface as the latitude approaches the poles. This phenomenon occurs in the Northern Atlantic and Pacific where shipping traffic tends to concentrate when following great circle paths across the oceans. The large amount of shipping combined with the shallow deep sound channel in these areas cause a directional noise field in the vicinity of a passive acoustic array which is located in the sound channel. This phenomenon accounts for the higher levels of directional ambient noise fields in the higher latitudes.
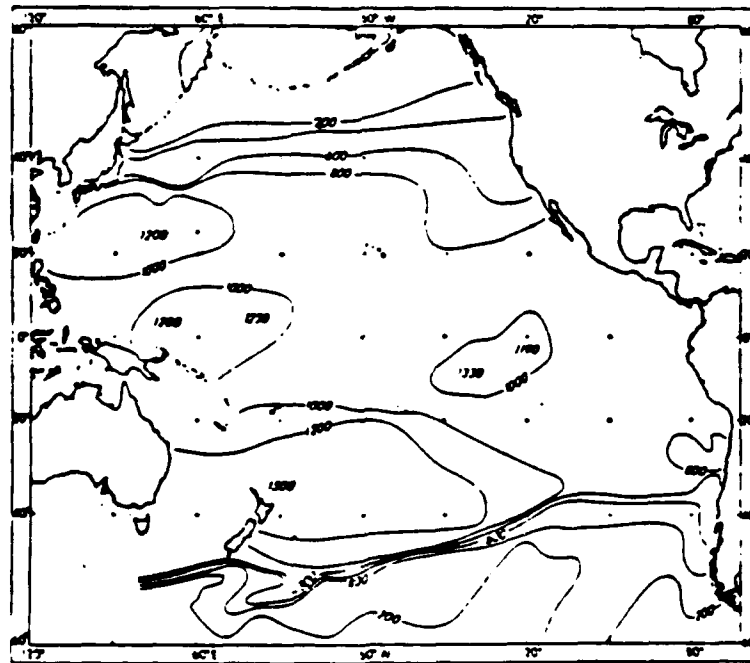
Figure 1. Depth of SOFAR axis in the Pacific Ocean. Contour interval 200 meters [Ref. 3].

The second mechanism accounting for shipping noise being trapped in the deep sound channel is the "downslope conversion

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phenomenon" [Ref. 2]. This describes the process of bottom reflected/surface reflected raypaths changing to refracted raypaths as the sound crosses over the continental shelf into the deep ocean basin and into the deep sound channel. Dense shipping normally found close to shore causes this phenomenon to cause significant directional noise towards the shore when operating off the continental shelf. Figure 2 displays both of these mechanisms occurring at the location marked on the chart. The lobe to the northwest can be attributed to the high levels of shipping traffic located south of the Aleutian Islands traveling along the great circle track between the Far East and North America. The lobe towards the northeast may be caused by the down-slope conversion of the sound of shipping on the continental shelf off the west coast of the United States [Ref. 4]. As the ASW mission moves from an open ocean, deep water scenario to a scenario closer in to shore, the down-slope conversion phenomenon will become a more important factor contributing to the directional nature of the ambient noise field.

B. OBTAINING THE DIRECTIONAL NOISE FIELD

The directionality of the noise field can be obtained from noise modeling based on historical data or from real time in-situ measurements. The in-situ measurements have the highest levels of confidence of being valid for a given scenario.

1. Noise Modeling

The amount of noise generated by distant shipping is directly proportional to the amount of shipping traffic present.
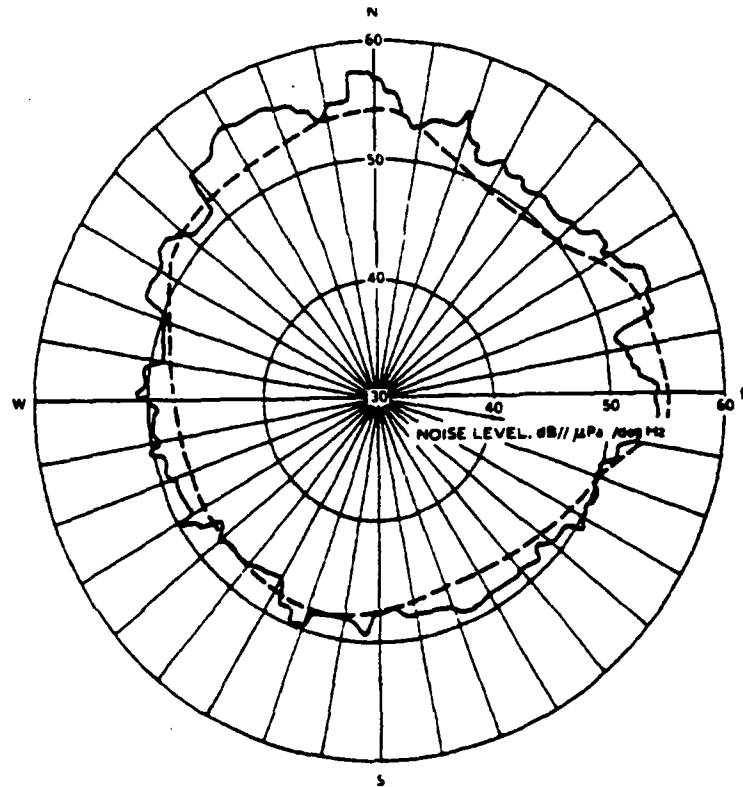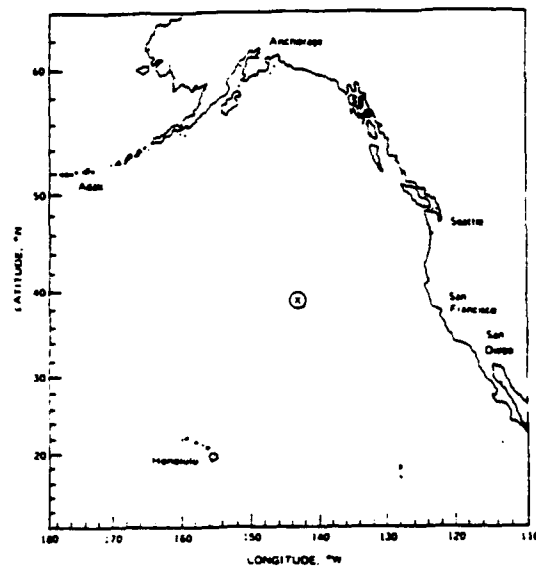
Figure 2. Horizontal Directionality of Ambient Noise. Site location marked by X on top. Directional patterns, as obtained with end-fire beam of line array (dashed) and with broadside beams (solid) on bottom [Ref. 2].

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Therefore, the directionality of the ambient noise field can be estimated by the amount and location of the shipping in the vicinity of the sensor. Historical data are available on the shipping density around the world and can be used to model the expected directional noise field for a given location at a given time of year. The environmental factors affecting sound transmission in the oceans must be modeled as well.

2. Noise Directionality Measurements

The most reliable way to obtain the directionality of the ambient noise field is to measure it with on board sensors. This can be done by performing any number of different towship maneuvers that will allow the measurement of beam noise data on three different array headings. In order to resolve the ambiguities, each heading must be at least forty degrees apart. Wagstaff's Iterative Technique [Ref. 5] is an ambiguity resolution and noise-field estimation algorithm which can be used to perform in-situ calculations of the directional noise field.

III. TOWED ARRAY BEAM PATTERN

A. BEAMWIDTH

All equations discussed below are taken from Lawrence J. Ziomek's book Underwater Acoustics [Ref. 6].

1. Beamwidth at Arbitrary Steering Angle

When a given towed array beam pattern is steered from broadside towards end-fire, the beamwidth increases. A minimum beamwidth value occurs at the broadside beam providing the finest bearing resolution. To compute the beamwidth, first assume that the array is linear and is oriented along the X axis. Next, let us calculate the beamwidth for the horizontal beam pattern. As seen in Figure 3, Ψ' is the steering angle in degrees, measured counter clockwise from the positive X axis. Also, let Ψ_+ and Ψ_- represent the angles corresponding to the 3-dB down points of the horizontal beam pattern. Note that Figure 3 shows both of the half-beamwidth angles to be equal to $\Delta\Psi/2$. Although this is not true in general, the resulting equation for $\Delta\Psi$ will still give accurate results.

In the XY plane the direction cosine u with respect to the X axis is given by

$$u = \cos(\Psi), \tag{1}$$

and will be used for calculation purposes. Therefore, let

$$u_+ = \cos(\Psi_+) > 0 \tag{2}$$

$$u_- = \cos(\Psi_-) > 0 \tag{3}$$

where

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$$u_+ > u_-, \tag{4}$$

$$\Psi_+ = \Psi' - (\Delta\Psi/2), \tag{5}$$

and

$$\Psi_- = \Psi' + (\Delta\Psi/2). \tag{6}$$
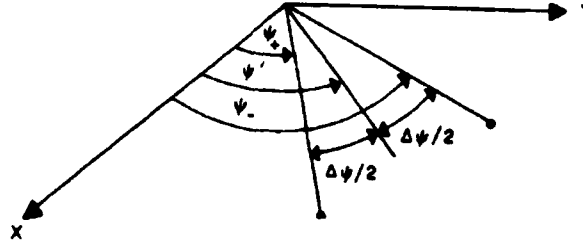
Figure 3. Representation of the beam steering angle Ψ' and the beamwidth $\Delta\Psi$ [Ref. 6].

Thus,

$$\Delta u = u_+ - u_- = 2\sin(\Psi')\sin(\Delta\Psi/2) > 0 \tag{7}$$

since

$$\cos(\alpha-\beta) - \cos(\alpha+\beta) = 2\sin(\alpha)\sin(\beta) \tag{8}$$

giving

$$\Delta\Psi = 2\sin^{-1}[\Delta u/2\sin(\Psi')], \tag{9}$$

where $\Delta\Psi$ is the beamwidth in degrees of the horizontal beam pattern centered at the angle Ψ'. Note that $\Psi' = \pi/2$ corresponds to the broadside beam pattern, and that $\Psi' = 0$ or π corresponds to the end-fire beam pattern where $\Delta u/2\sin(\Psi') = \infty$ and Eq. (9) is not valid. Equation (9) is only valid when $|\Delta u/2\sin(\Psi')| \le 1$. Therefore, a different approach must be used to determine the beamwidth at end-fire geometry.

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2. Beamwidth at End-Fire Geometry

Restricting ourselves to the horizontal beam pattern, consider the case when the steering angle, Ψ', is zero. Letting

$$u_- = \cos(\Psi_-) > 0 \tag{10}$$

and substituting $\Psi'=0$ into Eq. (6) yields

$$\Psi_- = \Delta\Psi/2. \tag{11}$$

For this case,

$$u' = \cos(\Psi') = \cos(0) = 1 \tag{12}$$

and

$$u_- = 1 - (\Delta u/2). \tag{13}$$

Combining Eq. (13) with Eqs. (3) and (11),

$$\cos(\Delta\Psi/2) = 1 - (\Delta u/2) \tag{14}$$

or

$$\Delta\Psi = 2\cos^{-1}(1 - (\Delta u/2)) \tag{15}$$

where $\Delta\Psi$ is the beamwidth in degrees of the endfire beams.

B. BEAMPATTERN

Consider a linear array composed of N (odd) identical, equally spaced, amplitude weighted elements. For the purposes of this thesis, only rectangular amplitude weights will be discussed. It is important to note that the theory pertains to all types of amplitude weighting. However, by limiting the discussion to rectangular amplitude weights, a closed form expression can be obtained for the directivity function of the array.

1. Directivity Function

The directivity function of a linear array can be expressed as a function of the frequency and the appropriate direction cosine, which in our case is direction cosine u. Figure 4 shows a typical normalized beam pattern steered in the direction u = u' in direction cosine space.
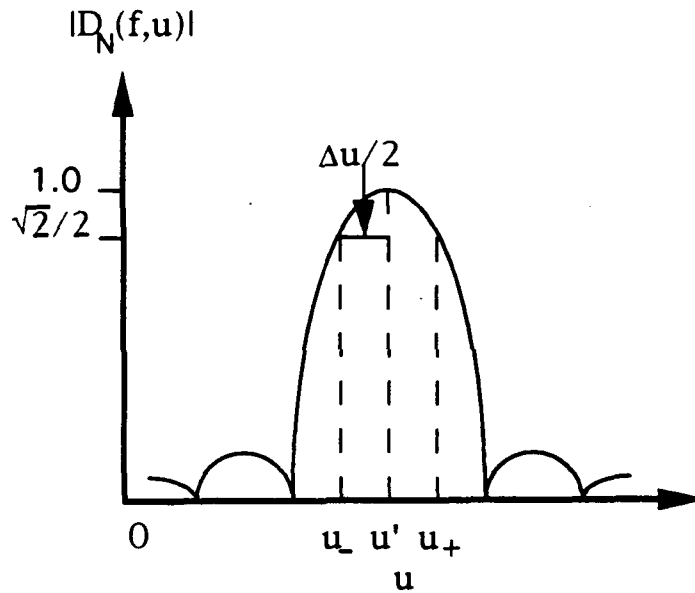
Figure 4. Magnitude of a typical normalized beam pattern steered in the direction u = u' in direction cosine space [Ref. 6].

The closed form expression for the normalized, horizontal directivity function of a linear array with rectangular amplitude weighting is

$$D_N(f,f_x) = \sin(\pi f_x N d)/N\sin(\pi f_x d) \qquad (16)$$

where

$$f_x = u/\lambda, \qquad (17)$$

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N is the number of elements in the array, d is the inter-element spacing, u is given by Eq. (1), and λ is the wavelength of the sound waves. Upon steering the beam, the resulting directivity function, $D_N'(f,f_X)$, is simply a translated version of the original directivity function, $D_N(f,f_X)$, that is,

$$D_N'(f,f_X) = D_N(f,f_X - f_X').\qquad(18)$$

Therefore, when steering the beam, Eq. (16) can still be used by replacing f_X with $f_X - f_X'$ where:

$$f_X - f_X' = (u - u')/\lambda.\qquad(19)$$

2. Beamwidth in Direction Cosine Space

To determine the 3-dB beamwidth, Δu, in direction cosine space for the normalized directivity function given by Eq. (16), set

$$\sin(\pi N d u_+/\lambda)/N\sin(\pi d u_+/\lambda) = 0.707\qquad(20)$$

or, rewriting,

$$\sin(N\pi x) - N(0.707)\sin(\pi x) = 0\qquad(21)$$

where

$$x = u_+ d/\lambda = \Delta u d/2\lambda,\qquad(22)$$

so that

$$\Delta u = 2\lambda x/d.\qquad(23)$$

Upon finding the solution to Eq. (21) for x and substituting the result into Eq. (23), the 3-dB beamwidth in direction cosine space is obtained.

IV. OPTIMAL LINEAR ARRAY HEADING

The towed linear array is one of the most valuable sensors on board any Naval ASW unit. The high levels of directivity obtained and the relatively high degree of mobility combine to make the towed linear array an effective ASW sensor. These two factors have also led to the common practice of placing the narrow broadside beam in the suspected direction of the target. This tactic has worked well in the fleet, especially when the ambient noise field is omnidirectional. However, in many cases where the ambient noise field is directional, this tactic can lead to a severe degradation of the towed array's performance. The interaction of the ambiguous beam with the ambient noise field can lead to a less than optimal noise level received by the array.

A. AMBIGUOUS BEAMS

The beamwidth of a linear array beam pattern has a minimum value at broadside and increases to a maximum value at the endfire beams. This conical beam pattern inherently presents a left-right ambiguity problem as seen in Figure 5. It is impossible to determine from which side of the array the sound is coming without maneuvering the array. Each beam of the array has a mirror image on the opposite side of the array commonly called the ambiguous beam. The ambiguous beam receives additional noise which, in many cases, raises the total noise level received by the array which

centers the main lobe of the beam pattern on the target. It is often possible to minimize the ambient noise arriving at the ambiguous beam by prudently choosing the heading that the array is oriented.
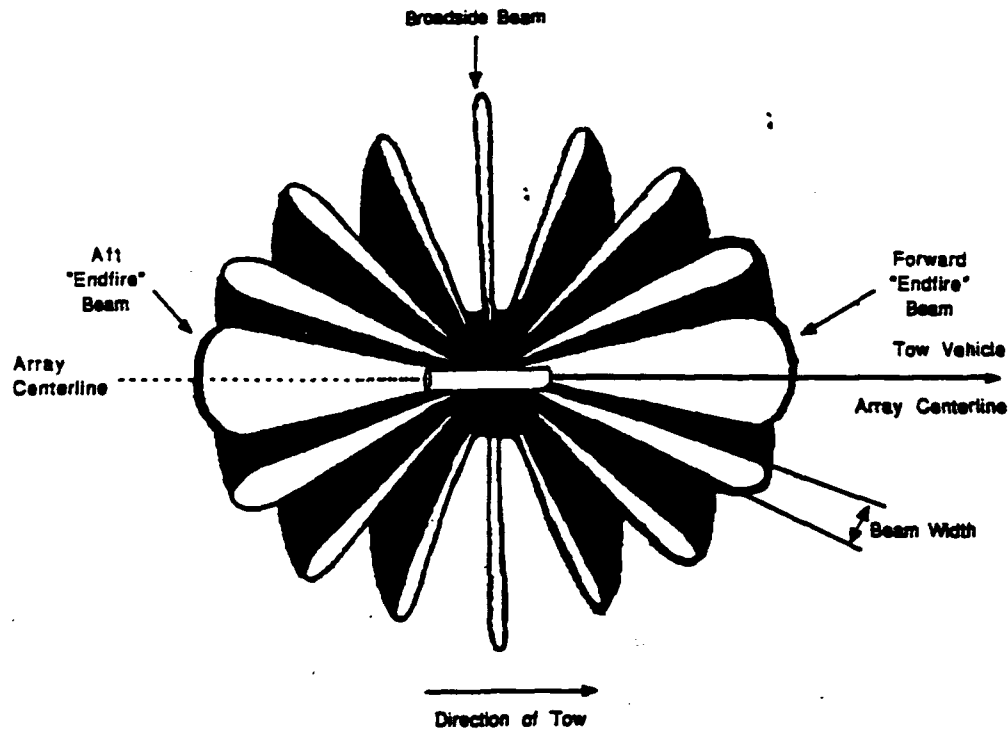
Figure 5. Generic Linear Array Beam Pattern.

B.   TOTAL NOISE LEVEL CALCULATION

When numerous individual noise sources are presented to a linear array, they must all be considered in determining the total noise level. Assuming that the individual noise levels are uncorrelated, the total noise level may be calculated using the following equation:

$$TNL = 10 \log(\Sigma_i 10^{(NL_i/10)}) \qquad (24)$$

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where NL_i are the individual noise levels in dB and TNL is the total noise level [Ref. 7].

C. OPTIMAL HEADING DETERMINATION

Figure 6 displays a directional ambient noise field in dB ref 1 µPa in 1 degree increments. The target's suspected location is to the northwest.
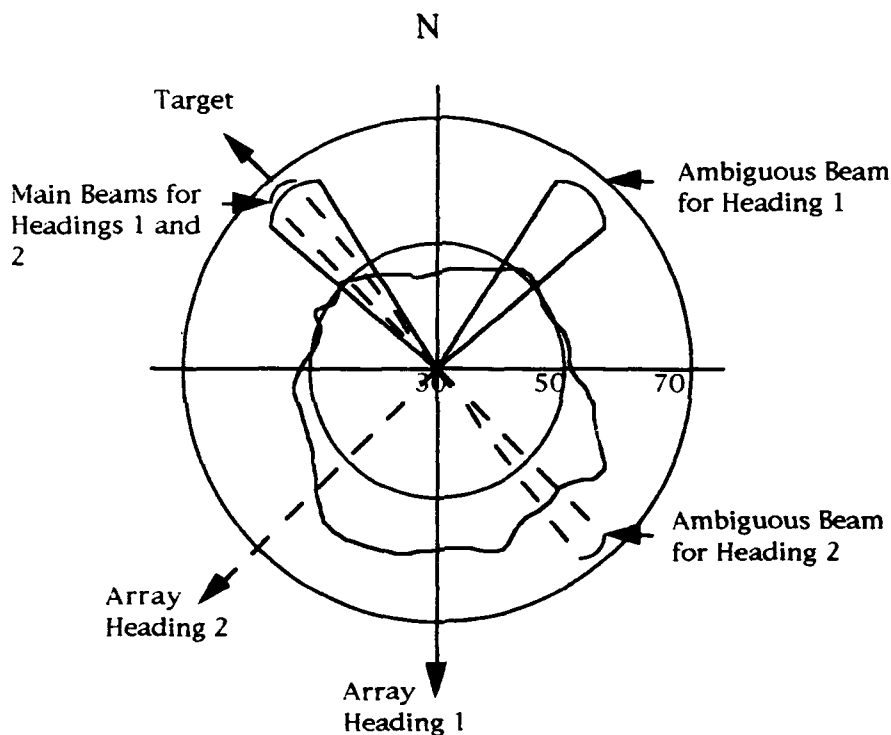
Figure 6. Illustration of the interaction of array beams and the ambient noise field.

Array heading 1 is to the south and places the target in beams about 45 degrees off of broadside (solid beam pattern). The ambiguous beam on heading 1 is located to the northeast where the ambient

noise averages about 50 dB. Using Eq. (24) and neglecting detailed beam pattern calculations, the approximate total noise level received for heading 1 is about 62 dB. Array heading 2 is to the southwest and places the target in the broadside beam (dashed beam pattern). The ambiguous beam for heading 2 is located to the southeast where the ambient noise level averages about 60 dB. Again using Eq. (24) and neglecting detailed beam pattern calculations, the total noise level received for heading 2 is about 67 dB. Array heading 1 receives a total noise level which is about 5 dB less than that of array heading 2. The SNR received on array heading 1 will subsequently be greater than the SNR received on the broadside array heading 2 and the probability of detection will likewise be proportionately higher. Assuming that the target's signal strength does not vary significantly over the time it would take to maneuver the array, heading 1 should be chosen over the broadside heading 2.

This technique can be used to determine the actual noise level detected by the array, including detailed calculations for the beam pattern, for all possible headings. The total noise levels detected for each heading can be compared with the noise levels for all the other possible headings to determine the heading which detects the minimal amount of noise. Thus, an optimal heading can be determined for the orientation of the array which maximizes the SNR detected by the array [Ref. 8].

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V. PROGRAM DESCRIPTION

The program in appendix A is provided to demonstrate the manner in which the optimal heading is obtained for a given directional noise field and for a suspected target location.

A. AMBIENT NOISE DATA

The program prompts the user to input the ambient noise field by one of two means. First, the user can input the name of a file where the ambient noise data is stored. This would correspond to a historical type of ambient noise data which has been stored in the computer at a previous time. The second means of inputting the ambient noise data is for the user to input the data directly into the computer. This process is somewhat cumbersome and takes about five to ten minutes depending on the complexity of the noise field, but the data is copied to a file for easy access at a later time. This corresponds to an in-situ ambient noise field measurement.

B. LINEAR ARRAY CHARACTERISTICS

The program simulates a linear array comprised of eleven omnidirectional hydrophones with an interelement spacing of five meters. The interelement spacing allows for optimal array performance for 150 Hz signals, which is the only frequency the program is capable of processing. The number of elements generate a broadside beam which is nine degrees wide and an endfire beam which is forty-six degrees wide. The characteristics of this array do

not correspond to any particular array, but are used purely to demonstrate that any array can be simulated with a similar program.

C. TARGET INFORMATION

The only information that is required concerning the target is the target's suspected true bearing. The user is prompted to input this information which the program uses to determine the relative bearings to the target for all possible headings that the array may be oriented. Additionally, the program determines the headings which place the broadside beam in the direction of the target. The broadside headings are used as a reference later in the program.

D. BEAM PATTERN DETERMINATION

For each possible heading, the main lobe is centered at the suspected location of the target. The program also determines the bearing at which the ambiguous beam is centered for each heading. The 3-dB beamwidths of the beams are determined using either Eq. (9) or Eq. (15), depending on the orientation of the target to the array. The program also determines the normalized beam pattern using Eq. (16). The true bearings which the main lobe and the ambiguous beam cover are determined for use in the noise calculation.

E. NOISE LEVEL CALCULATION

The program combines the beam pattern and the ambient noise field to determine the ambient noise level detected for each possible heading. The ambient noise level for each bearing which the beam covers is converted into a pressure, multiplied by the beam pattern

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factor, then summed together with the other noise levels in the same beam pattern using Eq. (24). After all the pressures are summed the total noise level is converted back into a dB level for later use. For each heading, the total noise level detected is compared to the reference broadside heading total noise level. The results are stored in a file which can later be displayed using another program.

F. PROGRAM LIMITATIONS

The program is capable of simulating one linear array and can only process noise data at 150 Hz. Additionally, only rectangular windowing is used when determining the beam pattern of the array. Future possible work could provide programs which can simulate multiple arrays and frequencies. Other types of windowing could also be incorporated into the program.

G. PROGRAM EXAMPLE

Figure 7 displays an ambient noise field at 150 Hz given in dB referenced to 1 μPa. The noise levels are given in one degree increments in degrees true. The higher noise levels are concentrated to the south while lower noise levels are found to the north. If the suspected location of the target is to the north, the broadside headings of 090 or 270 would place the main broadside lobe in the direction of the target. While these courses place the main lobe in the direction of the target, the ambiguous beam is directed towards the south in the direction of the higher ambient noise levels. Therefore, courses which still place the main lobe in the direction of the target, but place the ambiguous beam in areas of lower noise

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AMBIENT NOISE PLOT
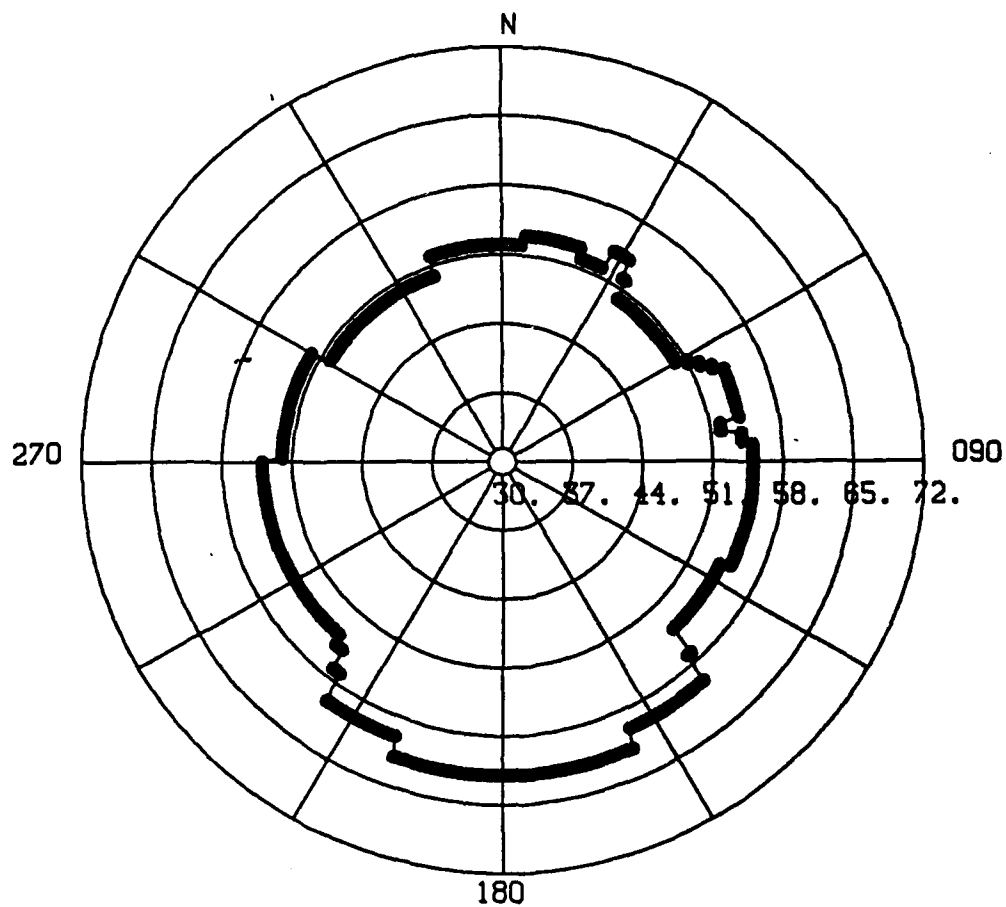
NOISE LEVELS GIVEN IN DB REF 1μPA

Figure 7. Directional ambient noise field at 150 Hz. Levels are given in dB ref 1 μPa.

levels may have lower total noise levels than the broadside headings. Even though the beamwidth of the array beam pattern is greater than the broadside beamwidth and more individual noise levels will be detected, the total noise level may be less than the broadside heading total noise level.

The optimal heading program was run for the case described above and the results are displayed in Figure 8. The SNR gain for each possible heading relative to the broadside heading are displayed. The possible headings are given in degrees true and the SNR gains are given in dB. Note that for the broadside headings of 090 and 270, the SNR gain is zero relative to broadside which is expected. As the array heading is changed from the broadside heading towards the north, the total noise level received by the array lowers and the SNR gain relative to the broadside heading increases. Note that when the array is oriented about 30 to 60 degrees off of broadside in any direction, the SNR gain is from 5 to 6 dB relative to the broadside heading. For this case the common practice of placing the broadside heading in the direction of the target degrades the performance of the array by about 6 dB. Additionally, the heading to orient the array on can be chosen to comply with any other constraints placed on the ASW unit.

Additional examples using various ambient noise fields are presented in Appendix B along with a discussion of each one.

SNR GAIN RELATIVE TO BROADSIDE HEADING
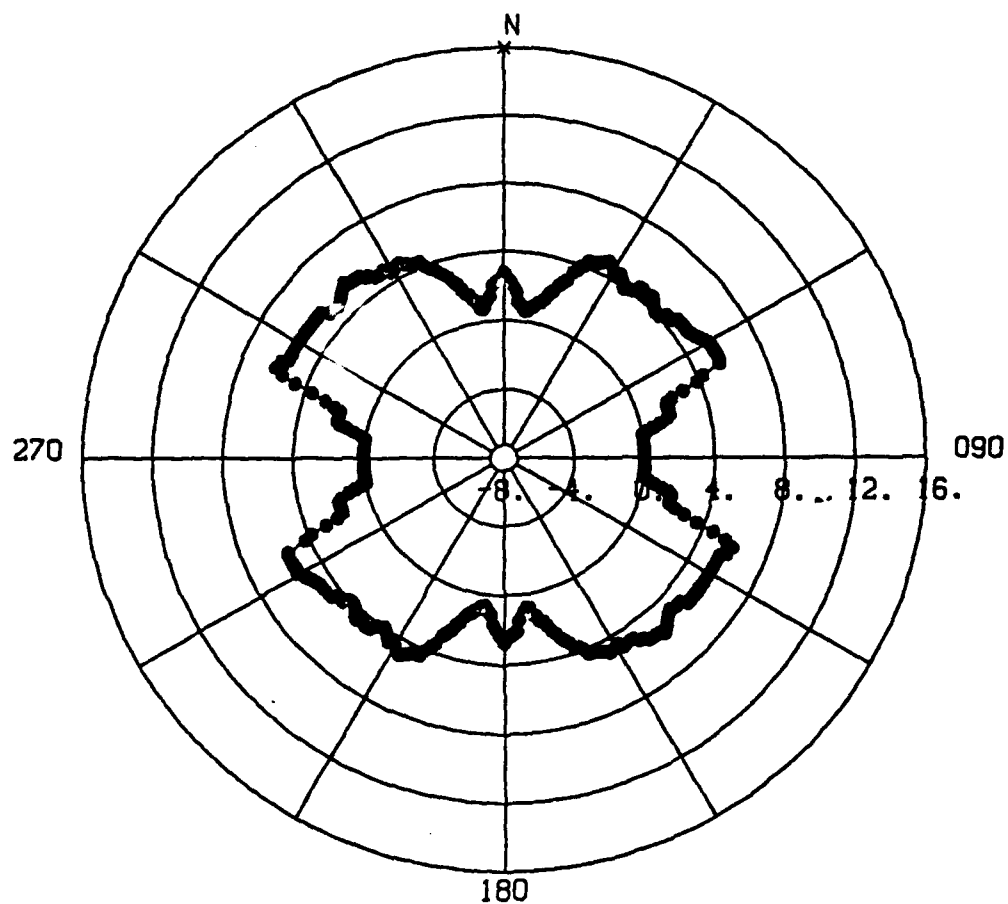
LEVELS GIVEN IN DB REF 1μPA

X - TARGET TRUE BEARING 360.

Figure 8. SNR gain for all true headings relative to the broadside heading.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The optimal array heading can, in many cases, significantly improve the SNR for a linear array in a directional noise field. Two major applications for the technique occur at different phases of a given ASW scenario. The first application occurs when planning to search an area for a target. The traditional barrier search is a prime example of this. The target's suspected location is known and there is plenty of time to consider the directional ambient noise field prior to setting up the barrier. The orientation of the barrier should be based upon the optimal array heading calculation for the given noise field.

The second major application occurs after a target has been detected. The ASW unit should place itself between the target and the direction of the highest ambient noise to prevent counterdetection from the target submarine while optimizing the unit's detection capabilities. Additionally, the ASW unit should choose the courses which optimize the array's SNR based on the optimal heading calculation.

B. RECOMMENDATIONS

Based on the results of this thesis, the following actions are recommended:

1. A computer program, such as in Appendix A, should be made up for each of the arrays in the US Navy's arsenal and distributed to the applicable ASW units capable of using them.

2. A fleetwide ambient noise directionality measurement procedure should be made up and distributed to the fleet. All ASW unit commanders should be advised to the practicality of measuring the ambient noise field and using the results to optimize the probability of detection.

3. A directional ambient noise data base should be established which can be made available to all ASW units.

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APPENDIX A
FORTRAN PROGRAMS

This appendix provides the reader with the program "Optimal" which is compiled using the FORTRAN language. The program calculates the optimal heading to search for a target in a directional ambient noise field. The program is described in detail in Chapter V. Additionally, two plotting programs are provided for display purposes. The first program, "Plot", displays the directional ambient noise field using the Disspla routine on the Naval Postgraduate School's mainframe computer. The second program, "Plot2", displays the results of the Optimal program using the Disspla routine also.

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C      DAVID C. MCDONNELL, LT, USN
C
C      ***************************************************************
C      *THIS PROGRAM CALCULATES THE OPTIMAL TOWED ARRAY HEADING IN  *
C      *A DIRECTIONAL NOISE FIELD ENVIRONMENT, MINIMIZING THE       *
C      *AMBIENT NOISE DETECTED BY THE SENSOR.                       *
C      ***************************************************************
C
C      VARIABLE DECLARATION SECTION
C
       CHARACTER*20 FILE1,FILE2,FILE3
       REAL X(360),Y(360),TGT,L(180),N1,N2,DN,HDG,DU,N,BW,DTHETA,DT1
       REAL DT2,DT3,DT4,PSUM,PI,ANS,LEVEL,BHEAD,PSY1P,PSY2P,F,F1
       REAL G(180),PSY1,DPSY1,PSY2,DPSY2
       INTEGER A,B,C,D,I,J,M,K,O,P,Q
C
C      ***************************************************************
C
C      VARIABLE DESCRIPTION SECTION
C
C      * FILE1, FILE2, AND FILE3 ARE USER FILES TO ACCESS AND STORE
C      INFORMATION.
C      *X(360) IS AN ARRAY WHICH STORES THE AMBIENT NOISE DATA
C      *Y(360) IS A DUMMY ARRAY HOLDING THE AMBIENT NOISE DATA
C      *TGT IS THE TARGETS TRUE BEARING
C      *L(180) IS AN ARRAY WHICH STORES THE AMBIENT NOISE LEVEL FOR
C      EACH HEADING BETWEEN 1 AND 180 TRUE
C      *N1 IS THE NOISE LEVEL AT THE BEARING OF THE TARGET
C      *N2 IS THE NOISE LEVEL AT THE AMBIGUOUS BEARING OF THE TARGET
C      *DN IS THE DIFFERENCE IN BEARING BETWEEN TARGET AND SENSOR
C      *HDG IS THE HEADING OF THE SENSOR
C      *DU IS A CONSTANT WHICH AFFECTS THE BEAMWIDTH OF THE ARRAY
C      *N IS THE NUMBER OF ELEMENTS IN THE ARRAY
C      *BW IS THE BEAMWIDTH OF THE ARRAY IN RADIANS
C      *DTHETA IS THE HALF-BEAMWIDTH OF THE ARRAY IN DEGREES
C      *DT1,DT2,DT3,DT4 ARE THE TRUE BEARINGS WITHIN THE MAIN BEAM
C      *PSUM IS THE SUM OF THE NOISE PRESSURES
C      *PI=3.141593
C      *ANS = ANSWER TO QUESTION
C      *LEVEL IS THE NOISE LEVEL IN DB OF THE AMBIENT NOISE REF 1UPA
C      *BHEAD IS THE BROADSIDE HEADING TO THE TARGET
C      *PSY1P AND PSY2P ARE THE ANGLES IN DEGREES CCW FROM THE SENSOR
C      HEADING TO THE TARGET AND THE AMBIGUOUS BEAMS
C      *F IS THE BEAM PATTERN FACTOR
C      *F1 IS A FACTOR USED IN CALCULATING THE BEAM PATTERN FACTOR
C      *G(180) IS THE ARRAY WHICH STORES THE GAIN FOR EACH HEADING
C      *PSY1,PSY2,DPSY1,DPSY2 ARE FACTORS USED TO CALCULATE THE BEAM
C      PATTERN FACTORS
C      *A,B,C,D,I,J,M ARE INTEGERS USED FOR NOISE FIELD INPUT
C      *K,O,P,Q ARE INTEGERS USED FOR THE GAIN CALCULATION
C
       PI=3.141593
C      ***************************************************************
C
C      OBTAIN THE AMBIENT NOISE DATA FROM THE USER
C
C      THE USER IS GIVEN A CHOICE TO USE EITHER A STORED DATA FIELD
C      OR TO CREATE HIS OWN DATA FIELD
C
5      WRITE(*,*)'PLEASE CHOOSE THE NUMBER CORRESPONDING TO THE '
       WRITE(*,*)'MEANS OF ENTERING THE AMBIENT NOISE FIELD'
       WRITE(*,*)'  '
       WRITE(*,*)'   1) OBTAIN DATA FROM AN EXISTING FILE'
       WRITE(*,*)'   2) USER INPUT DATA'
       READ(*,*,ERR=5) ANS
C
C      IF THE USER WANTS TO USE A STORED DATA FIELD
       IF(ANS.EQ.1) THEN
6              WRITE(*,*)'ENTER THE NAME OF THE FILE WHERE THE NOISE'
               WRITE(*,*)'DATA IS STORED'
               READ(*,'(A10)',ERR=6) FILE1
               OPEN(UNIT=1, FILE=FILE1, STATUS='OLD')
```

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          DO 20 I=1,360
          READ(1,*) X(I)
20        CONTINUE
          CLOSE (1)
          GO TO 70
C
C     IF THE USER WANTS TO CREATE HIS OWN DATA FIELD
      ELSE IF (ANS.EQ.2) THEN
      D=1
      M=1
C
21    WRITE (*,*) 'ENTER THE FILE WHERE YOU WISH THE NOISE'
      WRITE (*,*) 'LEVELS TO BE STORED'
      READ (*,'(A10)',ERR=21) FILE2
      OPEN (UNIT=2, FILE=FILE2, STATUS='UNKNOWN')
C
25    WRITE (*,26) D
26    FORMAT('ENTER THE NOISE LEVEL BEARING',1X,I3.3,1X,'DEG TRUE')
      WRITE (*,*)'(ENTER -99 TO END DATA ENTRY WHEN REACH BRG 360)'
      READ (*,*,ERR=25) LEVEL
C
      IF (LEVEL.EQ.-99) GO TO 60
29    WRITE (*,*)'ENTER THE BEARINGS WHICH CORRESPOND TO THIS LEVEL'
      WRITE (*,30) D
30    FORMAT ('STARTING WITH',1X,I3.3,1X,'DEG TRUE (EX. 001,010)')
      READ (*,*,ERR=29) A,B
      C=B-A+1
      D=B+1
C
C     THIS DO LOOP WRITES THE NOISE LEVELS TO THE FILE
C
      DO 50 J=1,C
          WRITE (2,40) LEVEL
40        FORMAT (1X,F6.2)
          X(M)=LEVEL
          M=M+1
50    CONTINUE
      GO TO 25
C
60    CLOSE(2)
C
70    END IF
C     ***************************************************************
C     ***************************************************************
C
C     THIS PROGRAM USES A GENERIC LINEAR ARRAY COMPOSED OF 7
C     ELEMENTS SPACED 5 METERS APART, GIVING THE ARRAY A LENGTH OF
C     50 METERS.  THIS SPACING IS SET UP FOR A FREQUENCY OF 150 HZ.
C     FOR PURPOSES OF BEAMWIDTH DETERMINATION THE FOLLOWING EQUATION
C     HAS PREVIOUSLY SOLVED FOR X.
C
C         SIN(N*PI*X)-N*.7071*SIN(PI*X)=0
C
C     RESULTING WITH X = .04041, AND DU=4*X GIVING:
C
      DU=.1616
      N=11
C
C     ***************************************************************
C     OBTAIN THE TARGET INFORMATION FROM THE USER
C
75    WRITE(*,*)'ENTER THE SUSPECTED TRUE BRG OF THE TARGET'
      READ(*,*,ERR=75) TGT
      IF (TGT.EQ.0) TGT = 360.
C
C     DETERMINE THE BROADSIDE HEADING BETWEEN 1 AND 180 FOR THE
C     GIVEN TARGET POSITION.
C
      BHEAD = TGT - 90
      IF (BHEAD.LE.0) THEN
          BHEAD = TGT + 90
      ELSE IF (BHEAD.GT.180) THEN
```

```
              BHEAD = BHEAD - 180
        END IF
C       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C
C
C       OBTAIN NAME FOR FILE WHERE SNR GAIN DATA IS TO BE STORED
C
80      WRITE (X,X)' ENTER FILENAME FOR SNR GAIN DATA STORAGE'
        READ (X,'(A10)',ERR=80) FILE3
        OPEN (UNIT=3, FILE=FILE3, STATUS='UNKNOWN')
C
        WRITE (3,X) TGT
C
C       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C
C
C       FOR EACH POSSIBLE HEADING THE LOOP CALCULATES THE GAIN
C       RELATIVE TO BROADSIDE THAT THE ARRAY ACHIEVES
C
        HDG = 1
C
        DO 200 K = 1,180
C
        N1=TGT
C
        DO 90 Q=1,360
        Y(Q)=X(Q)
90      CONTINUE
C
        DN=HDG - TGT
C
C       THE FOLLOWING IF STATEMENT DETERMINES THE AMBIGUOUS BEAM FOR
C       THE CURRENT HEADING
C
              IF (DN.GT.-360.AND.DN.LE.-180) THEN
              DN=DN+360
              N2=HDG+DN
              ELSE IF (DN.GT.-180.AND.DN.LT.180) THEN
              N2=HDG+DN
              ELSE IF (DN.GE.180.AND.DN.LE.360) THEN
              DN=360-DN
              N2=HDG-DN
              END IF
C
              IF (N2.GT.360) THEN
              N2=N2 - 360
              ELSE IF (N2.LT.0) THEN
              N2=N2 + 360
              END IF
C
        IF (N1.EQ.0) N1=360
        IF (N2.EQ.0) N2=360
C
C       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C
C
C       DETERMINE THE BEARING CCW FROM THE ARRAY FOR THE BEAM
C       CONTAINING THE TARGET AND THE AMBIGUOUS BEAM.  THESE RELATIVE
C       BEARINGS ARE USED IN CALCULATING THE BEAMWIDTH AND THE BEAM
C       PATTERN FACTOR USED BELOW
C
        IF (HDG.GE.TGT) THEN
              PSY1P=HDG-TGT
              PSY2P=360-PSY1P
        ELSE IF (HDG.LT.TGT) THEN
              PSY1P=HDG-TGT+360.
              PSY2P=360-PSY1P
        END IF
C
C       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C
C
C       DETERMINE THE BEAM WIDTH OF THE BEAM CONTAINING THE TARGET AS
C       WELL AS THE AMBIGUOUS BEAM.  THE 3 DB DOWN POINT IS USED TO
C       DETERMINE THE BEAMWIDTH OF THE BEAM PATTERN.
C
```

29

```
C       FOR ENDFIRE
C
        IF (PSY1P.EQ.0..OR.PSY1P.EQ.180.) THEN
              BW = 2*ACOS(1-(DU/2))
C
C       ELSE IF NOT ENDFIRE
C
        ELSE IF (PSY1P.NE.0..AND.PSY1P.NE.180.) THEN
              IF (DU/(2*ABS(SIN(PSY1P*PI/180))).LE.1) THEN
                    BW = 2*ASIN(DU/(2*ABS(SIN(PSY1P*PI/180))))
              ELSE IF (DU/(2*ABS(SIN(PSY1P*PI/180))).GT.1) THEN
                    BW = 2*ACOS(1-(DU/2))
              END IF
        END IF
C
C       DETERMINE THE HALF BEAMWIDTH OF THE BEAM IN DEGREES.
C
        DTHETA = INT(BW*180/(PI*2))
C
C       ****************************************************
C
C
C       CALCULATE THE TOTAL NOISE SEEN BY THE ARRAY ON THIS HEADING
C
        PSUM = 10**(X(INT(N1))/10) + 10**(X(INT(N2))/10)
C
C       THE FOLLOWING DO LOOP SUMS THE AMBIENT NOISE LEVELS WITHIN THE
C       BEAMS OF THE ARRAY.  THE BEAM PATTERN FACTOR, F, IS CALCULATED
C       FOR EACH NOISE LEVEL WITHIN THE BEAM.
C
        DO 100 O=1,DTHETA
C
C       NOISE LEVELS ARE SET TO ZERO AFTER COUNTING TO PREVENT THEM
C       FROM BEING COUNTED TWICE.
C
          DT1 = N1 + O
C
          IF (DT1.GT.360) DT1 = DT1 - 360.
          PSY1=PSY1P*PI/180.
          DPSY1=(PSY1P+O)*PI/180.
          F1=(PI/2)*(COS(PSY1)-COS(DPSY1))
          IF (F1.EQ.0) THEN
              F=1.
          ELSE
              F=SIN(N*F1)/(N*SIN(F1))
          END IF
          IF (F.LT.0.707) GO TO 92
C
          PSUM=PSUM+F*10**(Y(INT(DT1))/10)
          Y(INT(DT1))=0
C
92        DT2 = N2 + O
          IF (DT2.GT.360) DT2 = DT2 - 360.
C
          PSY2=PSY2P*PI/180.
          DPSY2=(PSY2P+O)*PI/180.
          F1=(PI/2)*(COS(PSY2)-COS(DPSY2))
          IF (F1.EQ.0) THEN
              F=1.
          ELSE
              F=SIN(N*F1)/(N*SIN(F1))
          END IF
          IF(F.LT.0.707) GO TO 94
C
          PSUM=PSUM+F*10**(Y(INT(DT2))/10)
          Y(INT(DT2))=0
C
94        DT3 = N1 - O
          IF (DT3.LE.0) DT3 = DT3 + 360
C
          DPSY1=(PSY1P-O)*PI/180.
          F1=(PI/2)*(COS(PSY1)-COS(DPSY1))
          IF (F1.EQ.0) THEN
```

```
            F=1.
         ELSE
            F=SIN(N*F1)/(N*SIN(F1))
         END IF
         IF (F.LT.0.707) GO TO 96
C
         PSUM=PSUM+F*10**(Y(INT(DT3))/10)
         Y(INT(DT3))=0
C
96       DT4 = N2 - O
         IF (DT4.LE.0) DT4 = DT4 + 360
C
         DPSY2=(PSY2P-O)*PI/180.
         F1=(PI/2)*(COS(PSY2)-COS(DPSY2))
         IF (F1.EQ.0) THEN
            F=1.
         ELSE
            F=SIN(N*F1)/(N*SIN(F1))
         END IF
         IF (F.LT.0.707) GO TO 100
C
         PSUM=PSUM+F*10**(Y(INT(DT4))/10)
         Y(INT(DT4))=0
C
100      CONTINUE
C
110      L(K)=10*LOG10(PSUM)
C
         HDG = HDG +1.
200      CONTINUE
C
C        THE FOLLOWING DO LOOP CALCULATES THE GAIN RELATIVE TO
C        BROADSIDE FOR EACH HEADING.
C
         DO 250 P = 1,180
C
C        FOR EACH HEADING THE GAIN RELATIVE TO THE BROADSIDE BEAM IS
C        CALCULATED AND PLACED INTO THE ARRAY G(P).
C
         G(P) =  L(INT(BHEAD)) - L(P)
C
         WRITE (3,*) G(P)
250      CONTINUE
C
C        THE FILE WHERE THE GAIN DATA IS STORED IS NOW CLOSED
C
         CLOSE (3)
C
         END
```

```
C       DAVID C. MCDONNELL, LT USN                                      PL000010
C       THIS PROGRAM USES THE DISSPLA ROUTINE TO PLOT THE AMBIENT NOISE PL000020
C       FIELD BEING USED.  THE USER MUST IDENTIFY THE FILE WHERE THE NOISEPL000030
C       DATA IS STORED.  A POLAR PLOT IS USED TO DISPLAY THE NOISE LEVEL PL000040
C       IN DEGREES TRUE.                                                PL000050
C                                                                       PL000060
C       VARIABLE DECLARATION SECTION                                    PL000070
C                                                                       PL000080
        INTEGER I,J                                                     PL000090
        REAL X(360),Y(360),Z(360),MIN,MAX,DR,DR1,DR2,DR3               PL000100
        CHARACTER*20 FILE$,FLN$                                         PL000110
C                                                                       PL000120
C       OBTAIN FILE NAME FROM THE USER                                  PL000130
C                                                                       PL000140
        WRITE (*,*)'ENTER FILENAME AND FILETYPE WHERE DATA IS STORED'   PL000150
        READ (*,'(A20)') FILE$                                          PL000160
C                                                                       PL000170
C       A "/" MUST BE APPENDED TO THE FILENAME FOR THE DISSPLA ROUTINE  PL000180
C       TO RECOGNIZE THE FILE.                                          PL000190
C                                                                       PL000200
        FLN$='/'//FILE$//'A'                                            PL000210
C                                                                       PL000220
        OPEN (UNIT=1,FILE=FLN$,STATUS='OLD')                            PL000230
C                                                                       PL000240
C       THE FOLLOWING DO LOOP READS THE AMBIENT NOISE FROM THE FILE.  THE PL000250
C       DISSPLA COMMAND "POLAR" PLOTS THE DATA REFERENCED TO RADIANS FROM PL000260
C       EAST.  THEREFORE, THE DEGREES TRUE ARE TRANSFORMED INTO RADIANS PL000270
C       FROM EAST FOR PLOTTING PURPOSES.                                PL000280
C                                                                       PL000290
C       INITIALIZE VARIABLES                                            PL000300
        MIN=100.                                                        PL000310
        MAX=0.                                                          PL000320
C                                                                       PL000330
        DO 10 I=1,360                                                   PL000340
           READ (1,*) X(I)                                              PL000350
C                                                                       PL000360
C       DETERMINE THE MINUMUM AND MAXIMUM NOISE LEVEL FOR PLOT PURPOSES PL000370
C                                                                       PL000380
           IF (X(I).LT.MIN) MIN=X(I)                                    PL000390
           IF (X(I).GT.MAX) MAX=X(I)                                    PL000400
C                                                                       PL000410
           IF (I.GT.0.AND.I.LT.90) THEN                                 PL000420
              J=90-I                                                    PL000430
           ELSE IF (I.GE.90) THEN                                       PL000440
              J=450-I                                                   PL000450
           END IF                                                       PL000460
           Y(J)=REAL(J)                                                 PL000470
           Z(J)=X(I)                                                    PL000480
C                                                                       PL000490
10      CONTINUE                                                        PL000500
C                                                                       PL000510
C       SET MIN/MAX EQUAL TO +/-10 THAN THE ACTUAL MIN/MAX NOISE LEVEL  PL000520
C       FOR PLOTTING PURPOSES.                                          PL000530
        MIN=INT(MIN)-20.                                                PL000540
        MAX=INT(MAX)+10.                                                PL000550
        DR=INT((MAX-MIN)/6.)                                            PL000560
        DR1=MIN+DR                                                      PL000570
        DR2=DR1+DR                                                      PL000580
        DR3=DR2+DR                                                      PL000590
        DR4=DR3+DR                                                      PL000600
        DR5=DR4+DR                                                      PL000610
        MAX=DR5+DR                                                      PL000620
C                                                                       PL000630
        DR=2*DR                                                         PL000640
C                                                                       PL000650
C                                                                       PL000660
C       THE PLOTTING ROUTINE USES DISSPLA COMMANDS TO PLOT THE DATA     PL000670
C       IN DEGREES TRUE WITH THE AMBIENT NOISE LEVELS GIVEN IN DB REF   PL000680
C       1 UPA.                                                          PL000690
C                                                                       PL000700
        CLOSE(UNIT=1)                                                   PL000710
        CALL SHERPA('MCT3NOIS','A',3)                                   PL000720
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C       CALL CX41 (4107)                                              PL000730
        CALL PAGE (8.5,11.)                                           PL000740
        CALL AREA2D(6.,6.)                                            PL000750
        CALL HEADIN ('AMBIENT NOISE PLOT',20,1.,1)                    PL000760
        CALL POLAR(.01745,DR,3.,3.)                                   PL000770
        CALL POLORG (MIN)                                             PL000780
        CALL GRID(-30,2)                                              PL000790
        CALL MARKER (15)                                              PL000800
        CALL CURVE(Y,Z,360,1)                                         PL000810
        CALL REALNO(MIN,+0,2.8,2.7)                                   PL000820
        CALL REALNO(DR1,+0,3.3,2.7)                                   PL000830
        CALL REALNO(DR2,+0,3.8,2.7)                                   PL000840
        CALL REALNO(DR3,+0,4.3,2.7)                                   PL000850
        CALL REALNO(DR4,+0,4.8,2.7)                                   PL000860
        CALL REALNO(DR5,+0,5.3,2.7)                                   PL000870
        CALL REALNO(MAX,+0,5.8,2.7)                                   PL000880
        CALL MESSAG('NOISE LEVELS GIVEN IN DB REF 1UPA',34,1.0,-1.0)  PL000890
        CALL MESSAG('N',1,3.0,6.1)                                    PL000900
        CALL MESSAG('180',3,2.8,-.2)                                  PL000910
        CALL MESSAG('090',3,6.2,3.0)                                  PL000920
        CALL MESSAG('270',3,-.5,3.0)                                  PL000930
        CALL ENDPL (0)                                                PL000940
        CALL DONEPL                                                   PL000950
        STOP                                                          PL000960
        END                                                           PL000970
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C       DAVID C. MCDONNELL, LT USN                                  PL000010
C       THIS PROGRAM USES THE DISSPLA ROUTINE TO PLOT THE AG DATA   PL000020
C       GENERATED FROM THE OPTIMAL PROGRAM.  THE PROGRAM READS THE  PL000030
C       DATA FROM THE FILE AND PLOTS THE DATA ON A POLAR PLOT.      PL000040
C       THE SHIPS HEADINGS AREREPRESENTED IN DEGREES TRUE AND THE   PL000050
C       AMPLITUDE OF THE AG IS REPRESENTED IN DB REF 1 UPA.         PL000060
C                                                                   PL000070
C       VARIABLE DECLARATION SECTION                               PL000080
C                                                                   PL000090
        INTEGER I,J,K                                               PL000100
        REAL X(360),Y(360),Z(360),A,B,MIN,MAX,DR,DR1,DR2,DR3,TGT    PL000110
        REAL DR4,DR5,STEP,T1                                        PL000120
        CHARACTER*20 FILE$,FLN$                                     PL000130
C                                                                   PL000140
C       OBTAIN THE FILE NAME FROM THE USER WHERE THE DATA IS STORED PL000150
C                                                                   PL000160
        WRITE(*,*)'ENTER FILENAME AND FILETYPE WHERE DATA IS STORED'PL000170
        READ(*,'(A20)') FILE$                                       PL000180
C                                                                   PL000190
C       A / MUST BE APPENDED TO THE FRONT OF THE FILENAME FOR THE   PL000200
C       DISSPLA PROGRAM TO RECOGNIZE IT.                           PL000210
C                                                                   PL000220
        FLN$='/'//FILE$//'A'                                        PL000230
C                                                                   PL000240
C       INITIALIZE VARIABLES                                        PL000250
C                                                                   PL000260
        A=0.                                                        PL000270
        MIN=100.                                                    PL000280
        MAX=0.                                                      PL000290
C                                                                   PL000300
C       THE FOLLOWING DO LOOPS READ THE DATA FROM THE FILE.  THIS IS DONE PL000310
C       THICE DUE TO THE RECIPROCAL HEADINGS WILL HAVE THE SAME AG. PL000320
C                                                                   PL000330
        DO 20 I=1,2                                                 PL000340
        OPEN (UNIT=1,FILE=FLN$,STATUS='OLD')                        PL000350
        READ(1,*)TGT                                                PL000360
        IF (TGT.LE.90) T1=90-TGT                                    PL000370
        IF (TGT.GT.90) T1=450-TGT                                   PL000380
           DO 10 J=1,180                                            PL000390
           A=A+1                                                    PL000400
           READ (1,*) X(INT(A))                                     PL000410
C                                                                   PL000420
C       DETERMINE THE MINIMUM AND MAXIMUM VALUE OF DATA FOR PLOT PURPOSES PL000430
C                                                                   PL000440
        IF (X(INT(A)).LT.MIN) MIN=X(INT(A))                         PL000450
        IF (X(INT(A)).GT.MAX) MAX=X(INT(A))                         PL000460
C                                                                   PL000470
C       THE DISSPLA POLAR COMMAND PLOTS ANGLES IN RADIANS FROM EAST. PL000480
C       THEREFORE DEGREES TRUE ARE CONVERTED TO RADIANS FROM EAST IN PL000490
C       THE FOLLOWING IF STATEMENTS.                               PL000500
C                                                                   PL000510
           IF (A.GT.0.AND.A.LT.90) THEN                            PL000520
              B=90-A                                                PL000530
           ELSE IF (A.GE.90) THEN                                  PL000540
              B=450-A                                               PL000550
           END IF                                                  PL000560
        Y(INT(B))=REAL(B)                                           PL000570
        Z(INT(B))=X(INT(A))                                         PL000580
C                                                                   PL000590
10         CONTINUE                                                 PL000600
        CLOSE (1)                                                   PL000610
20         CONTINUE                                                 PL000620
C                                                                   PL000630
C       SET MIN/MAX EQUAL TO +/- 10 FOR PLOTTING PURPOSES           PL000640
C                                                                   PL000650
        MIN = MIN - 10.                                             PL000660
        MAX = MAX + 10.                                             PL000670
        DR=INT((MAX-MIN)/6)                                         PL000680
        STEP=2*DR                                                   PL000690
        IF ((0-MIN).GE.(3*DR)) THEN                                 PL000700
           DR4=0                                                    PL000710
           DR3=DR4-DR                                               PL000720
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        DR2=DR3-DR                                              PL000730
        DR1=DR2-DR                                              PL000740
        MIN=DR1-DR                                              PL000750
        DR5=DR4+DR                                              PL000760
        MAX=DR5+DR                                              PL000770
      ELSE IF ((0-MIN).LT.(3*DR)) THEN                          PL000780
        DR2=0                                                   PL000790
        DR1=DR2-DR                                              PL000800
        MIN=DR1-DR                                              PL000810
        DR3=DR2+DR                                              PL000820
        DR4=DR3+DR                                              PL000830
        DR5=DR4+DR                                              PL000840
        MAX=DR5+DR                                              PL000850
      END IF                                                    PL000860
C                                                               PL000870
C     THE PLOTTING ROUTINE USES DISSPLA COMMANDS TO PLOT THE DATA  PL000880
C     IN DEGREES TRUE WITH LEVELS GIVEN IN DB REF 1UPA.         PL000890
C                                                               PL000900
      CALL SHERPA('MCT5DATA','A',3)                             PL000910
C     CALL CX41(4107)                                           PL000920
      CALL PAGE (8.5,11.)                                       PL000930
      CALL AREA2D(6.,6.)                                        PL000940
      CALL HEADIN ('SNR GAIN RELATIVE TO BROADSIDE HEADING',38,1.,1)  PL000950
      CALL POLAR(.01745,STEP,3.,3.)                             PL000960
      CALL POLORG (MIN)                                         PL000970
      CALL GRID (-30,2)                                         PL000980
      CALL MARKER(4)                                            PL000990
      CALL CURVE(T1,MAX,1,-1)                                   PL001000
      CALL MARKER (15)                                          PL001010
      CALL CURVE (Y,Z,360,1)                                    PL001020
      CALL REALNO(MIN,+0,2.8,2.7)                               PL001030
      CALL REALNO(DR1,+0,3.3,2.7)                               PL001040
      CALL REALNO(DR2,+0,3.8,2.7)                               PL001050
      CALL REALNO(DR3,+0,4.3,2.7)                               PL001060
      CALL REALNO(DR4,+0,4.8,2.7)                               PL001070
      CALL REALNO(DR5,+0,5.3,2.7)                               PL001080
      CALL REALNO(MAX,+0,5.8,2.7)                               PL001090
      CALL MESSAG('LEVELS GIVEN IN DB REF 1UPA',28,1.3,-1.0)    PL001100
      CALL MESSAG('N',1,3.0,6.1)                                PL001110
      CALL MESSAG('180',3,2.8,-.2)                              PL001120
      CALL MESSAG('090',3,6.2,3.0)                              PL001130
      CALL MESSAG('270',3,-.5,3.0)                              PL001140
      CALL MESSAG('X = TARGET TRUE BEARING',23,1.3,-1.4)        PL001150
      CALL REALNO(TGT,+0,4.2,-1.4)                              PL001160
      CALL ENDPL (0)                                            PL001170
      CALL DONEPL                                               PL001180
      STOP                                                      PL001190
      END                                                       PL001200
```

APPENDIX B

ADDITIONAL EXAMPLES

Examples of the "Optimal" program, along with a discussion of each, are included in this appendix. The first three examples are test cases which partially validate the program, and the other examples show the applicability of the program, depicting the SNR gain achievable in some cases when optimal heading selection is used.

A. EXAMPLE 1

Example 1 uses an omnidirectional ambient noise field which has a level of 50 dB as seen in Figure 9. In this case the broadside heading should be the optimal heading due to the narrow beamwidth of the broadside beams. Figure 10 shows the results of the "Optimal" program for this case with the suspected target location bearing 090. Notice the highest SNR gain is for the headings oriented towards the north and the south, the broadside headings. As the linear array's orientation is changed away from the broadside headings, the SNR gain becomes negative. Thus, the array's performance is degraded by up to about 4 dB when the array is oriented to place the target in the endfire beams. When the array is oriented to place the target just off of endfire, the array's performance is even worse than that of the endfire headings. This is due to the fact that the main lobe and the ambiguous beam overlap and a large heart shaped beam pattern is formed which has a larger beamwidth than that of the endfire beam.

AMBIENT NOISE PLOT
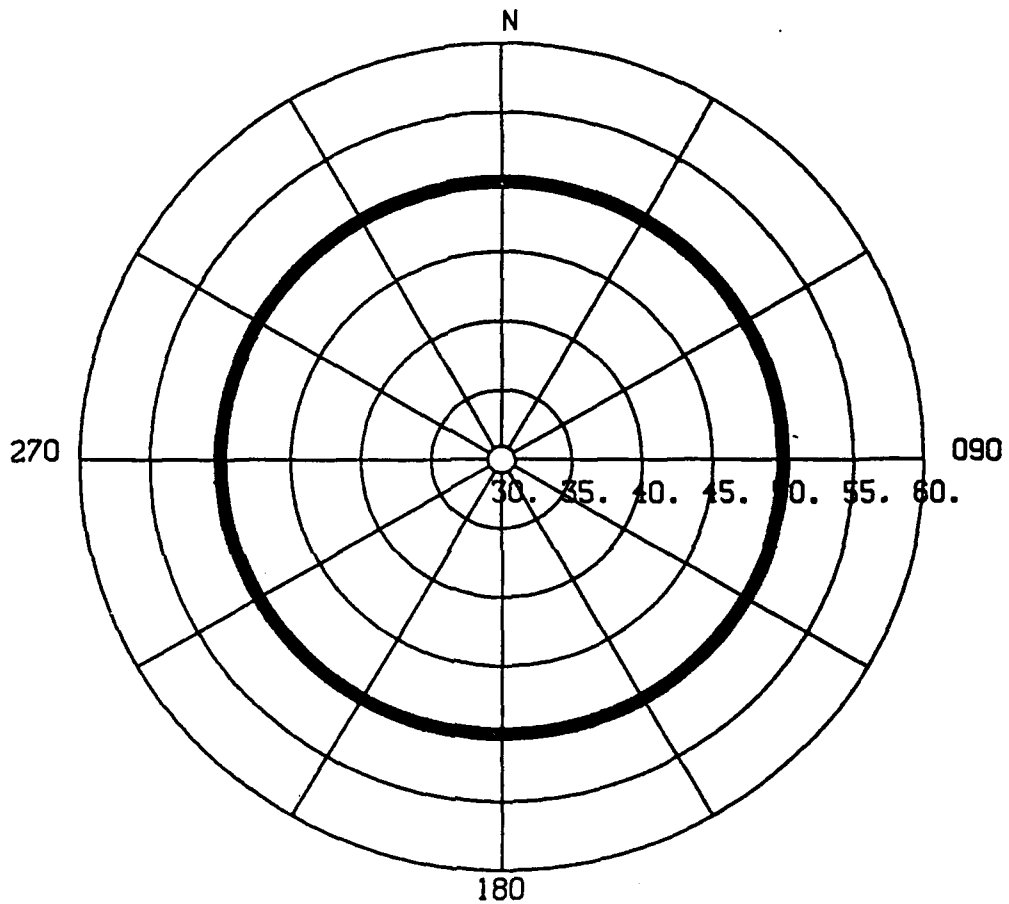
NOISE LEVELS GIVEN IN DB REF 1μPA

Figure 9. Omnidirectional ambient noise field at 150 Hz. Levels are given in dB ref 1 μPa.

SNR GAIN RELATIVE TO BROADSIDE HEADING
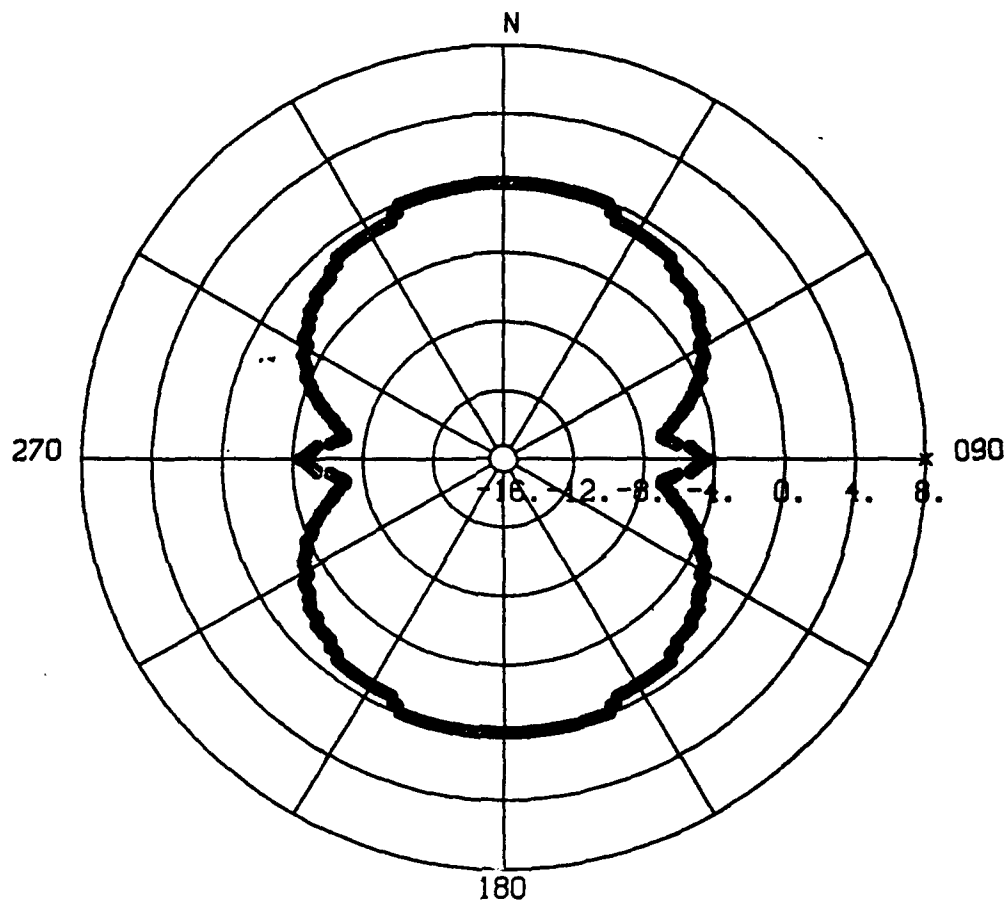
LEVELS GIVEN IN DB REF 1μPA

X - TARGET TRUE BEARING 90.

Figure 10. SNR gain for all true headings relative to the broadside heading.

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B.   Example 2

Example 2 provides another test case which is presented to partially validate the "Optimal" program. An ambient noise field which has a very high noise level at just one true bearing, 090, was created and is displayed in Figure 11. With the suspected target location to the west, the broadside headings of 000 and 180 would place the ambiguous beam in the direction of the high noise level at 090 and the array performance would be severely degraded. Any heading which does not place the array's ambiguous beam in the direction of the high noise level will have a significant SNR gain relative to the broadside heading. As can be seen in Figure 12, the SNR gain for almost all headings is anywhere from 11 to 18 dB higher than the SNR for the broadside heading. Figure 12 shows the results of the array's performance as the ambiguous beam passes through the high noise level located at 090. Note the curved pattern of the SNR gain plot in Figure 12 showing the inverted beam pattern of the array for the headings which place the ambiguous beam in the high noise level area. Additionally, total noise level calculations using Eq. (24) verify the program's result of the 18 dB SNR gain for the headings just off broadside.
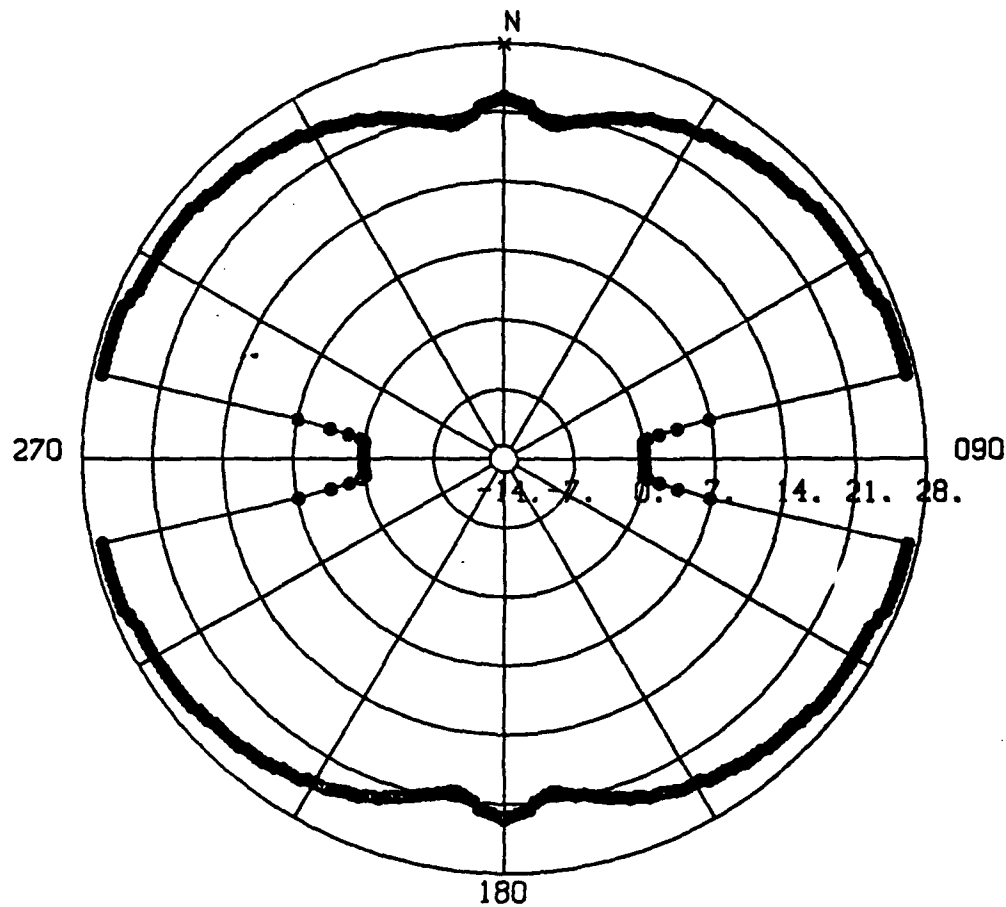
AMBIENT NOISE PLOT
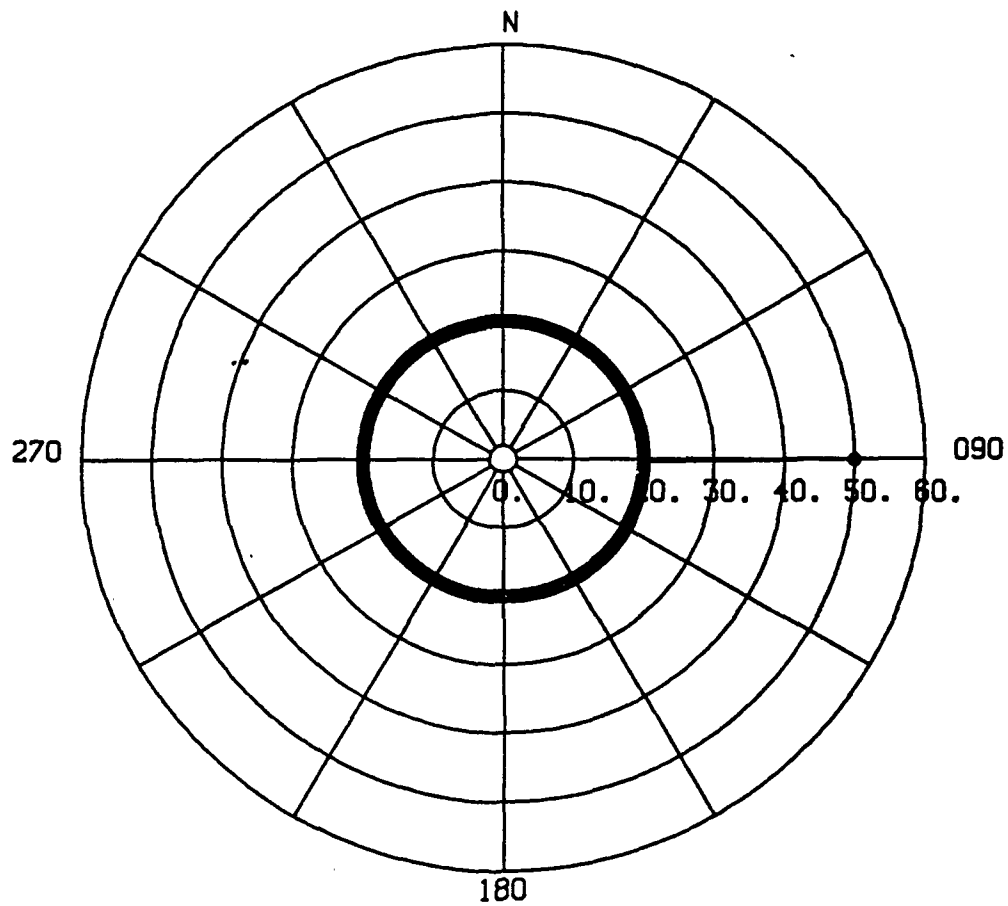
NOISE LEVELS GIVEN IN DB REF 1μPA

Figure 11. Highly directional ambient noise field at 150 Hz. Levels are given in dB ref 1 μPa. Note the high noise level located at a true bearing of 090.

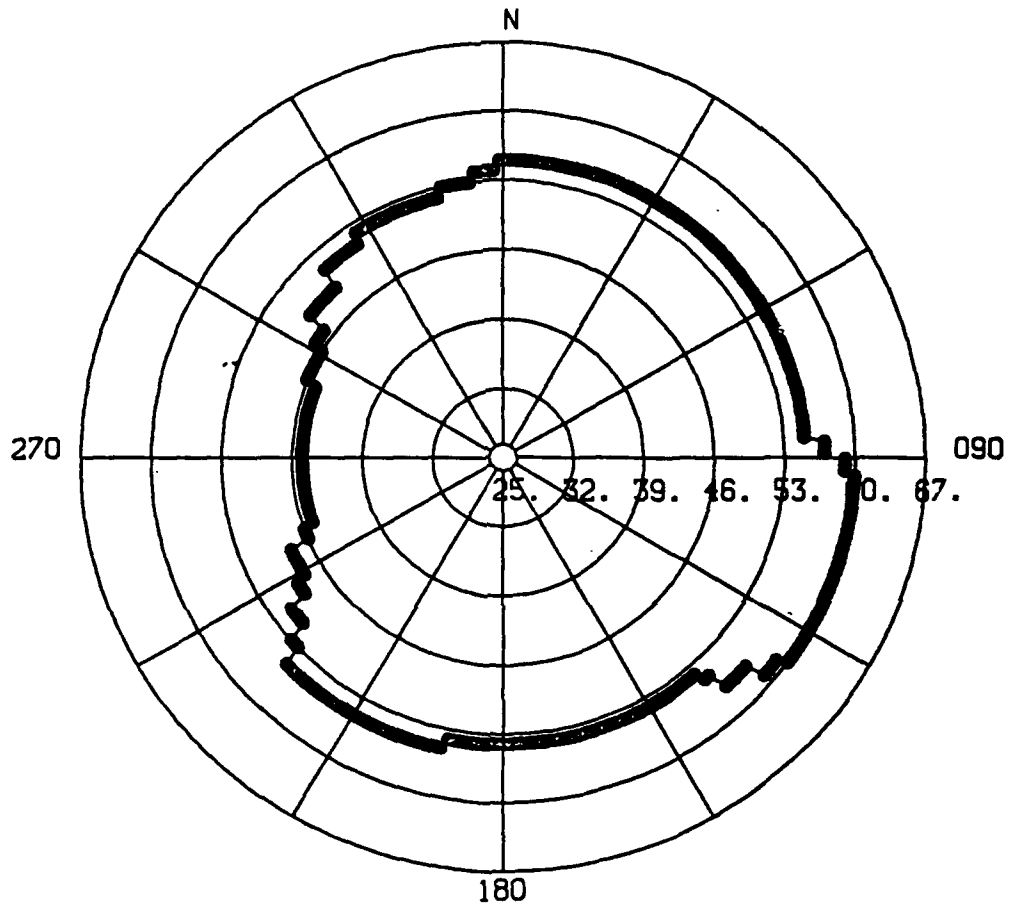SNR GAIN RELATIVE TO BROADSIDE HEADING
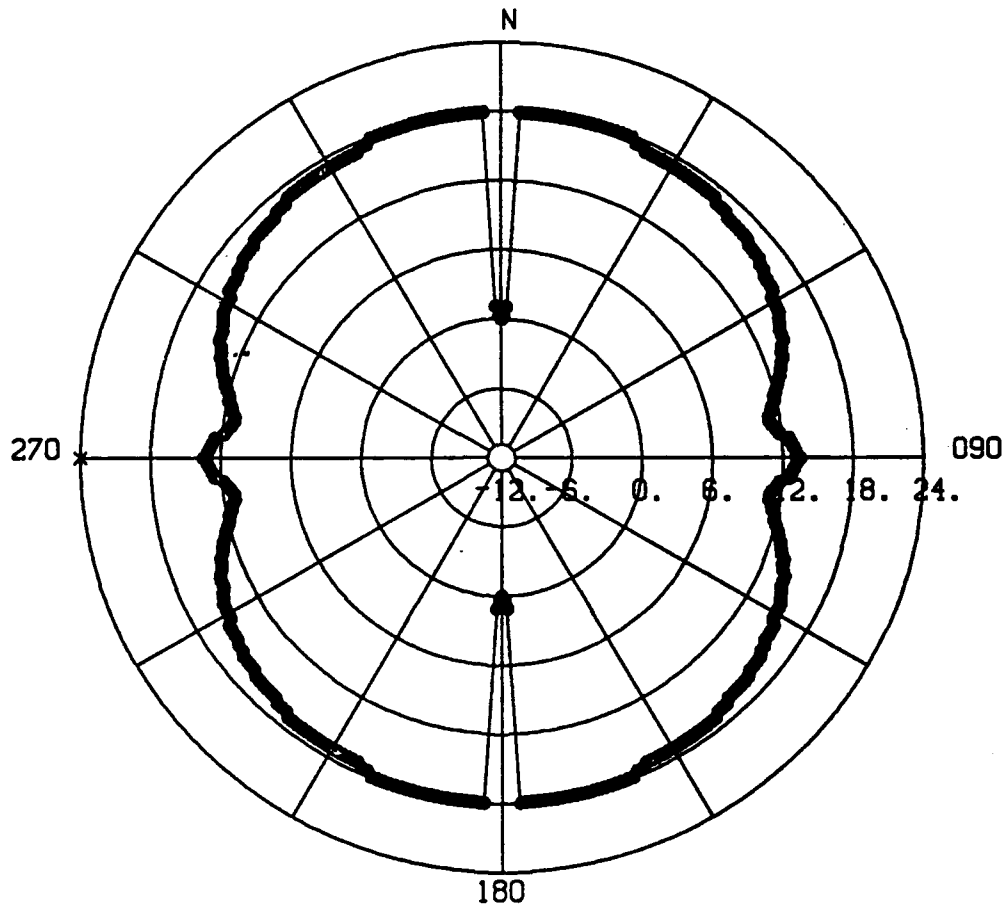
LEVELS GIVEN IN DB REF 1μPA

X - TARGET TRUE BEARING 270.

Figure 12. SNR gain for all true headings relative to the broadside heading in a highly directional noise field. Note the inverted beam pattern for array orientation of 000 and 180.

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C.   EXAMPLE 3

Example 3 is another highly directional ambient noise field which is used to partially validate the "Optimal" program. In this case very high noise levels of 80 dB, compared with the rest of the noise field, are located between true bearing of 160 and 200 as seen in Figure 13. With the suspected target location towards the north, the broadside headings of the array place the ambiguous beam in the direction of the high noise levels. The array's performance will be degraded for headings which place the ambiguous beam in the high noise level area. Figure 14 shows the results of the "Optimal" program for this case. The SNR gain for all headings which do not place the ambiguous beam in the high noise level area perform much better than the broadside headings of 090 and 270. Again the inverted beam pattern of the array is represented centered about the broadside headings. The constant SNR level of 0 dB gain results when the entire ambiguous beam is in the high noise level area. As the ambiguous beam starts to exit out of the high noise level area, the SNR gain gradually increases up to 27 dB, at which point none of the ambiguous beam is in the high noise level area. Total noise level calculations using Eq. (24) verify the program's result of a 27 dB gain for the headings just off broadside, which do not place the ambiguous beam in the high noise level area.

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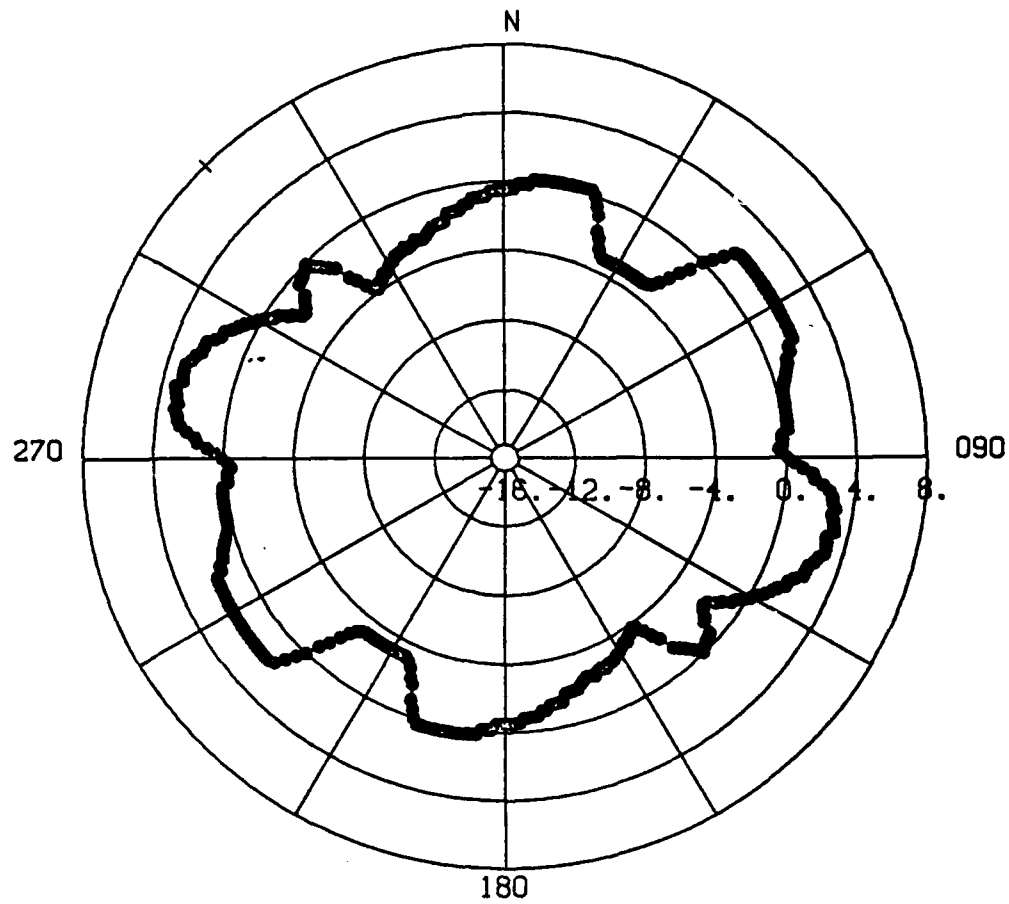
AMBIENT NOISE PLOT
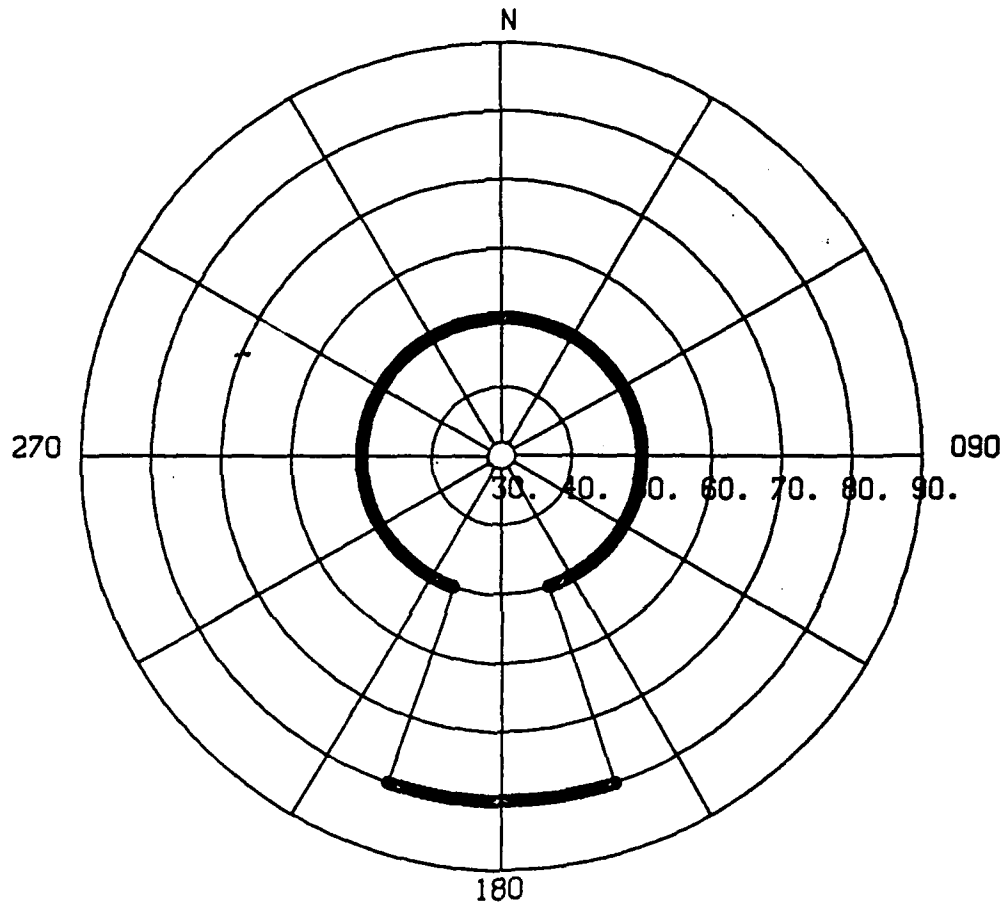
NOISE LEVELS GIVEN IN DB REF 1μPA

Figure 13. Highly directional ambient noise field at 150 Hz. Levels are given in dB ref 1 μPa. Note the high noise level located towards the south.

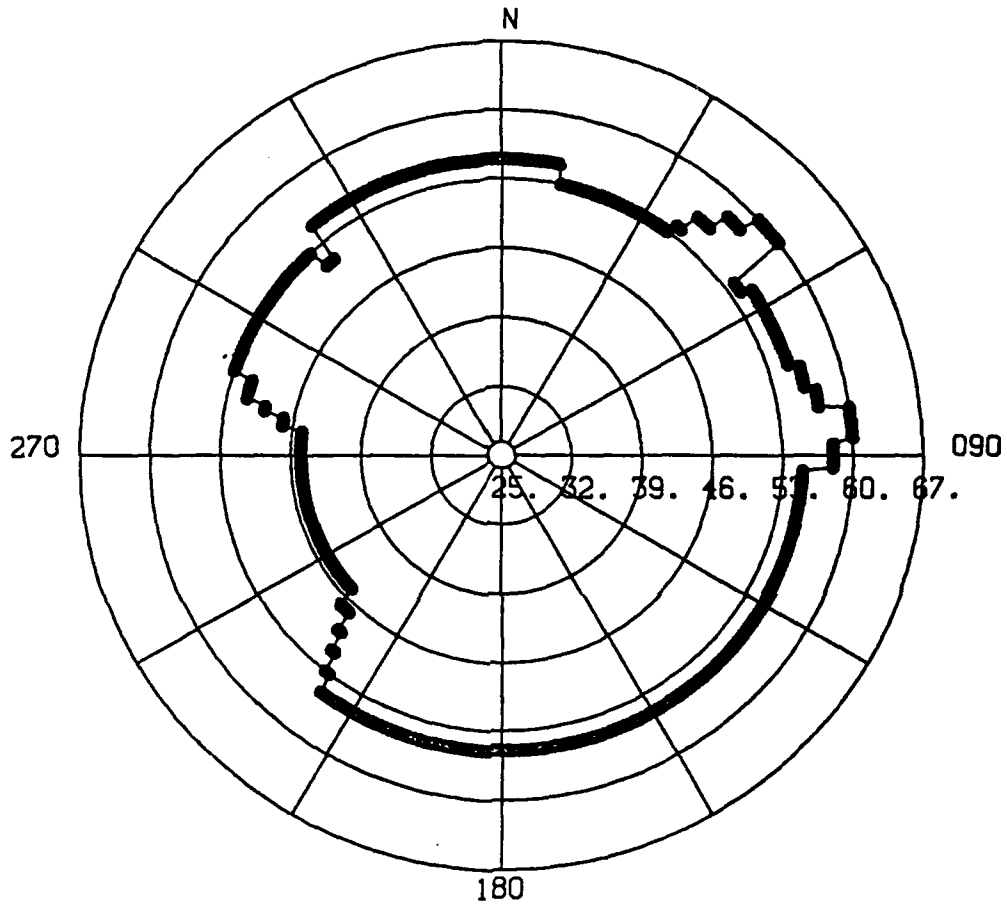SNR GAIN RELATIVE TO BROADSIDE HEADING

LEVELS GIVEN IN DB REF 1μPA

X - TARGET TRUE BEARING 360.

Figure 14. SNR gain for all true headings relative to the broadside heading in a highly directional noise field.

D. EXAMPLE 4

Figure 15 displays an actual ambient noise field. Noise levels vary from a high of about 60 dB towards the east-southeast to a low of about 45 dB towards the west. The "Optimal" program was used to analyze for a suspected target location towards bearing 315. As seen in Figure 16, gains of up to 3 dB can be obtained by choosing the appropriate array headings in this case. For instance, choosing a array heading of about 285 will produce a SNR gain of 3 dB relative to the broadside heading of 045.

Figure 15. An actual directional ambient noise field at 150 Hz.
Levels are given in dB ref 1 μPa.

Figure 16. SNR gain for all true headings relative to the broadside heading in an actual directional noise field.

E.   EXAMPLE 5

Figure 17 is an example of an actual ambient noise field which has two high noise level peaks of 60 dB at true bearings of about 050 and 085. Additionally, the noise levels toward the west-southwest are lower with levels of only about 45 dB. The "Optimal" program was run for this case and the results are displayed in Figure 18. Note the large variation in the SNR gain with relatively small changes in array heading. For instance, for an array heading of 330, a 4 dB SNR gain is achieved, but for an array heading of about 335, the ΛNR gain is -2 dB. A 6 dB difference in array performance is obtained with only a change of 5 degrees in array orientation. The two peaks in the ambient noise field are responsible for the high variability in the SNR gain in this case.
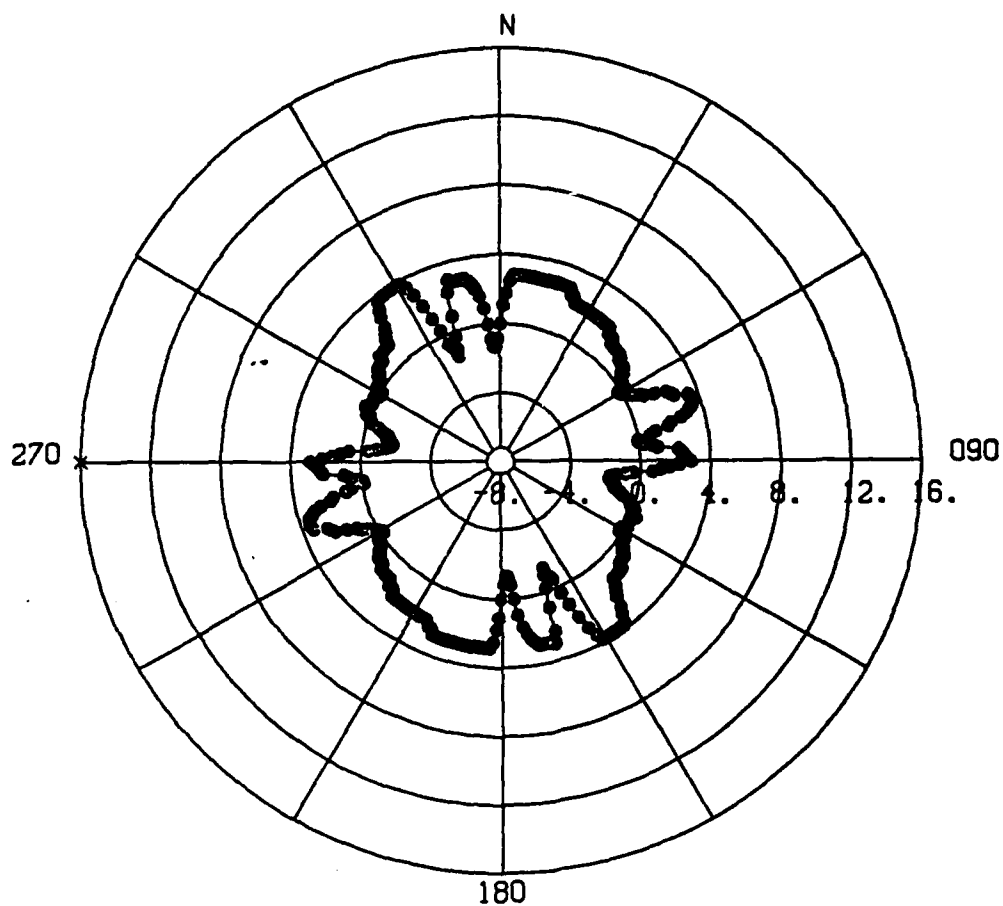
AMBIENT NOISE PLOT

Figure 17. An actual directional ambient noise field at 150 Hz. Levels are given in dB ref 1 μPa.

SNR GAIN RELATIVE TO BROADSIDE HEADING

LEVELS GIVEN IN DB REF 1μPA

X – TARGET TRUE BEARING   270.

Figure 18. SNR gain for all true headings relative to the broadside
heading in an actual directional noise field.

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